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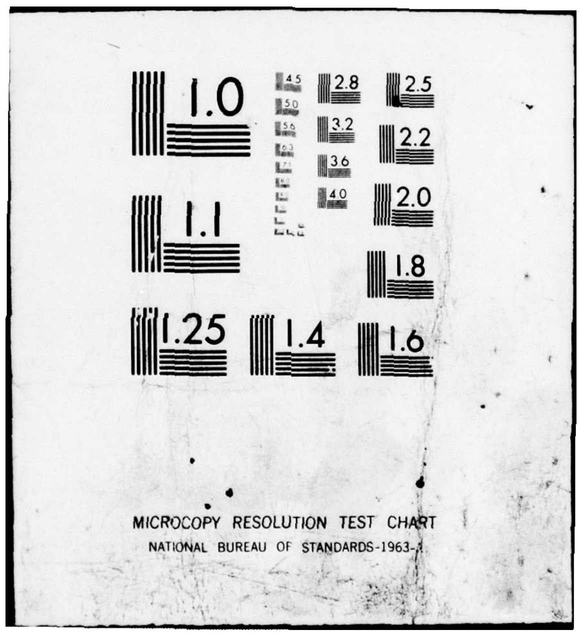
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# DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20084

DTNSRDC/PAS-79-31



## DEVELOPMENT OF REVERSE OSMOSIS DESALINATION FOR LIFE RAFT EMERGENCY DRINKING WATER SUPPLIES

By

J. F. Pizzino and W. L. Adamson



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PROPULSION AND AUXILIARY SYSTEMS DEPARTMENT
RESEARCH AND DEVELOPMENT REPORT



December 1979 DTNSRDC/PAS-79-31

DEVELOPMENT OF REVERSE OSMOSIS DESALINATION FOR LIFE RAFT EMERGENCY DRINKING WATER SUPPLIES

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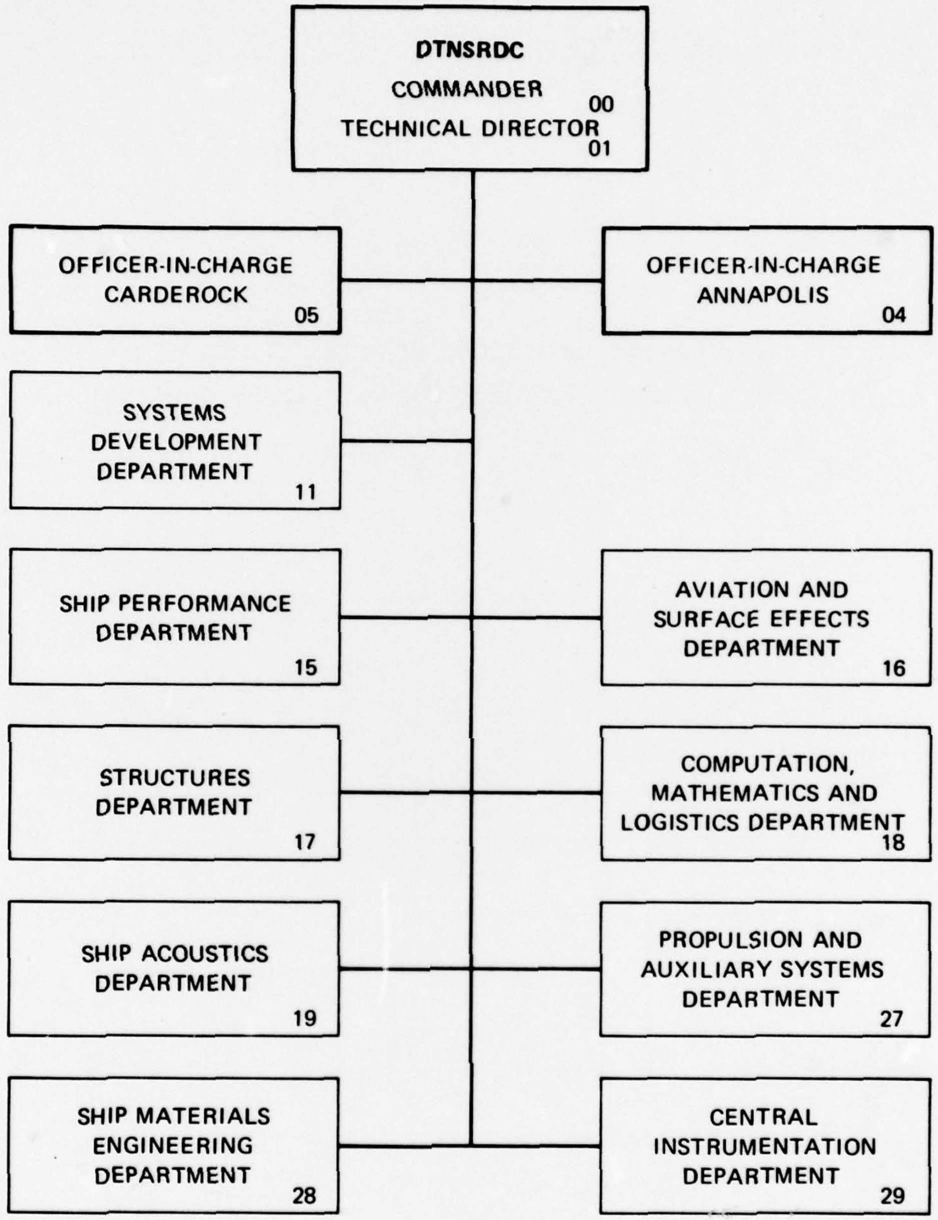

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Two hand-operated reverse osmosis desalinators being developed to provide emergency drinking water for life rafts were evaluated. Following some initial operating tests, the better performing unit, incorporating an energy recovery mechanism, was operated on a life raft in the open ocean by two Navy enlisted men for 7½ hours. Each man alternately pumped the unit for up to

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## TABLE OF CONTENTS



## LIST OF FIGURES

## LIST OF TABLES

## LIST OF ABBREVIATIONS

| | |
|---|---|
| $^{o}C$ | Degree Celsius |
| $^{o}F$ | Degree Fahrenheit |
| $ft^3$ | Cubic feet |
| gal/d | Gallon per day |
| gal/h | Gallon per hour |
| i.e., | That is |
| $m^3$ | Cubic meters |
| min | Minute |
| mm | Millimeter |
| NAVSEC | Naval Ship Engineering Center |
| No. | Number |
| ppm | Parts per million |
| psig | Pounds per square inch gage |
| RO | Reverse osmosis |

## ABSTRACT

Two hand-operated reverse osmosis desalinators being developed to provide emergency drinking water for life rafts were evaluated. Following some initial operating tests, the better performing unit, incorporating an energy recovery mechanism, was operated on a life raft in the open ocean by two Navy enlisted men for 7 1/2 hours. Each man alternately pumped the unit for up to 35 minutes each hour and produced better than 1 gallon-per-hour of drinking-quality water. The tests demonstrated the feasibility of using such a device to provide emergency drinking water on a Navy life raft.

## ADMINISTRATIVE INFORMATION

This report was completed as part of Naval Sea Systems Command Program Element 63514N, Subproject S0384SL, Task 15969, Work Unit 2745-102. The program manager is Mr. Carl Pohler, Naval Sea Systems Command (SEA 32R). All data in this report were taken in United States customary units.

## INTRODUCTION

### BACKGROUND

Most Navy commissioned ships today are equipped with Mark 5 and 6 emergency life rafts which are designed for 15 and 25 men, respectively. Each of these life rafts is encapsulated with a survival gear bag which contains emergency tools, first aid kit, and food and water supplies. Of this gear, a substantial portion of the weight and volume are attributable to water supplies. In the survival gear bag supplied with the Mark 6 life raft, for example; the water supply takes up approximately 1.5 $ft^3$* ($0.042\ m^3$) and weighs approximately 150 pounds (330 kilograms).

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*Definitions of abbreviations appear on page v.

The water rations provided in the current Navy survival gear provides at most a total of 1 1/2 quarts (1.42 liter) per man per life raft. This conforms to Coast Guard regulations[1*] which call for a minimum of 3 pints of water per man per life raft. Conversely, the Manual of Naval Preventative Medicine[2] requires as an absolute minimum of 1 gallon of water per man per day. It is apparent that the actual survival water requirements for life rafts is not a well defined quantity. What is most important is the fact that <u>the current life raft water supply is limited to a finite amount rather than a continuous supply.</u>

There are numerous accounts[3] of men who died at sea in life rafts from a lack of water. Most of these accounts are about Navy airmen who were downed at sea or Navy seamen whose ships were sunk. Basically, man can sustain life for longer periods of time without food than without water. Water survival requirements vary with conditions. It has been shown[4] that a man can be expected to survive in the shade without water for 2 to 10 days at shade temperatures of $120^{o}$ to $50^{o}$ F ($49^{o}$ to $10^{o}$ C), respectively. With a total of 2 quarts of water, a man can be expected to live 2 to 12 days at shade temperatures of $120^{o}$ and $50^{o}$ F, respectively. It is clear, therefore, that the 1 1/2 quarts of water per man provided in the survival gear bag do not significantly increase the life expectancy of a man stranded in a life raft.

During peacetime, it would be unlikely that a ship would be sunk and that survivors would be lost at sea for lengthy periods of time. During wartime, however, the possibility of such an occurrence would conceivably be high. Therefore, there should be considerable merit in providing life raft survival packages with a device which could continuously convert seawater to drinking water. Such a device could provide sufficient water to sustain life for as long as water is required.

The Center has been working on the development of a hand-operated RO desalinator for eventual stowage in Navy life raft survival bags. It is projected that such a device which could provide as much as 1 gallon of

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*A complete listing of references is given on page 21.

water per man per day on a continuous basis, would weigh less than 20 pounds and require less than 1/2 $ft^3$ to stow. Compared to present life raft water supplies which weigh 150 pounds, occupy 1 1/2 $ft^3$, and are capable of providing only a limited water volume, the RO desalinator looks to be a promising alternative.

There have in the past been two problems associated with the development of a hand-operated RO desalination device for life raft application: (1) the lack of a high-salt-rejection membrane, and (2) the prohibitively high manual energy requirements for operation of the high-pressure pump. New high-salt-rejection membranes have been developed through research programs sponsored by the Department of Interior Office of Water Research and Technology. The second problem associated with the development of a hand-operated RO unit has been resolved by the utilization of energy recovery techniques.

## SCOPE

This report covers the results of testing intended to demonstrate the feasibility of operating a hand-operated RO desalinator in an actual Navy life raft. Life raft testing was accomplished by Navy personnel in a Mark 5 life raft in two environments: (1) a pool and (2) the open ocean.

# REVERSE OSMOSIS DESALINATION

## BASIS OF REVERSE OSMOSIS

Reverse osmosis is a process whereby pressurized seawater is forced through a semipermeable membrane which selectively rejects salt in much the same manner as a filter rejects impurities. High-pressure seawater is continuously fed to one side of a sheet of membrane material. Ten to 30 percent of the feed seawater passes through the membrane as permeate (drinking water) while the resulting concentrated seawater is continuously dumped back overboard.

For convenience, the membrane is fabricated into a modular structure to facilitate replacement and handling. The RO membrane module then is installed in some type of cylindrical pressure vessel that is capable of

accommodating the normal operating pressure. A spiral-wrapped RO membrane module in which a "membrane sandwich" is wrapped around a central cylinder (or pipe) is shown in Figure 1. The spiral membrane module was the type used for both RO units evaluated.

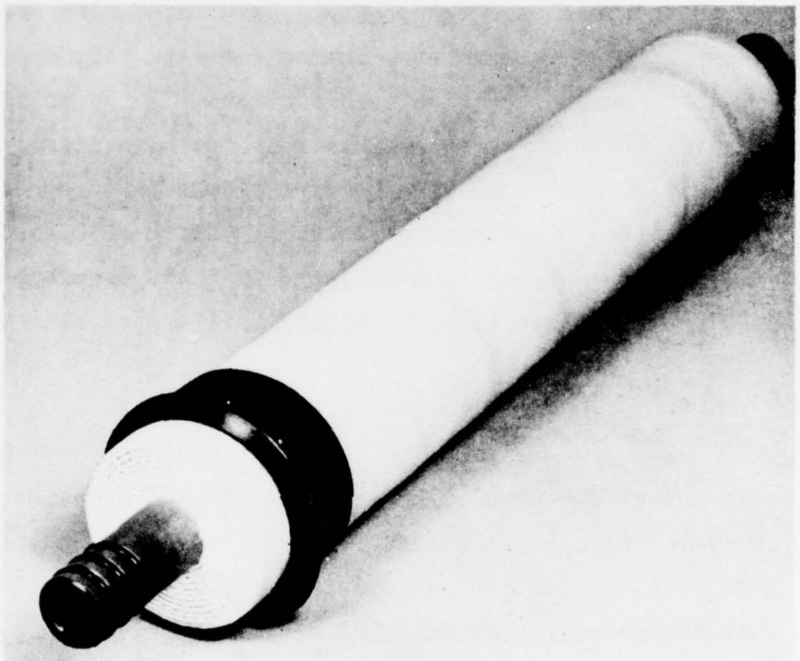

Figure 1 - Spiral-Wrapped Reverse Osmosis Membrane Module

TYPICAL REVERSE OSMOSIS UNIT

Figure 2 illustrates the operation of a typical RO unit for life raft application. Seawater containing 35,000 to 40,000 ppm salt is fed to a hand-operated pump which pressurizes it to 800 to 1,000 psig. From there, it enters the RO membrane module. Permeate having less than 1,500 ppm salt exits the RO module and is channeled to a container for drinking. The remaining 70 to 90 percent of the feed seawater exits the RO module as a concentrated brine. The brine is throttled from its operating pressure down to atmospheric pressure and then pumped overboard.

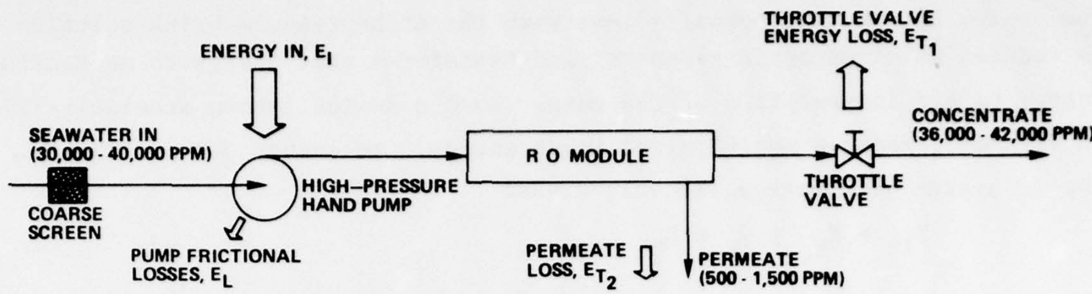


Figure 2 - Manually Operated Reverse Osmosis System

REVERSE OSMOSIS UNIT ENERGY RECOVERY

To understand the concept of an RO system with energy recovery, an understanding of the energy requirements for a typical RO unit is required. An energy balance on the RO system in Figure 2 gives:

$$E_I = E_{T_1} + E_{T_2} + E_L \tag{1}$$

where $E_I$ = the energy input to the system or the energy to operate the pump.

$E_{T_1}$ = the energy lost in throttling the high-pressure brine.

$E_{T_2}$ = the energy lost in reducing the pressure of the permeate across the membrane and in accomplishing chemical separation of the salts. (Chemical separation energy, which is equal to the heat of solution of the salt in water is very small and can be neglected.)

$E_L$ = the frictional energy losses associated with the high-pressure pump.

If a positive displacement pump is used in this application, the term $E_L$ will be an order of magnitude lower than the other terms in Equation (1). Because the throttle valve passes 70 to 90 percent of the original pressurized seawater, term $E_{T_1}$ is 2 1/2 to 9 times greater than $E_{T_2}$ and, therefore, represents the greatest contribution to $E_I$ in Equation (1).

The RO energy recovery device replaces the throttle valve and recovers the energy $E_{T_1}$ that is normally lost when the high-pressure brine solution is reduced to atmospheric pressure, and transforms that energy to mechanical energy to aid in operation of the pump. Such a device, shown schematically in Figure 3, reduces the required input energy. An energy balance for the the RO system with energy recovery gives:

$$E_{IR} = E_{T_2} + E_L + E_{RL} \tag{2}$$

where $E_{IR}$ = the energy required by the RO system with energy recovery

$E_{RL}$ = the energy losses associated with the energy recovery device.

The value $E_{RL}$ is a function of the efficiency of the energy recovery device and can be expressed as:

$$E_{RL} = E_{T_1} (1-\eta) \tag{3}$$

where $\eta$ = the efficiency of the energy recovery device.

Substituting Equation (3) into Equation (2) and subtracting Equation (2) from Equation (1) and rearranging, we obtain:

$$E_{IR} = E_I - \eta E_{T_1} \tag{4}$$

Equation (4) illustrates that the required energy input to an RO unit with energy recovery is that energy required to operate a unit without energy recovery minus the product of the throttle energy and the efficiency of the energy recovery device. Since $E_{T_1}$ represents the largest energy loss of the RO system, Equation (4) shows that with an efficient RO energy recovery device, the energy required by an RO unit can be substantially reduced.

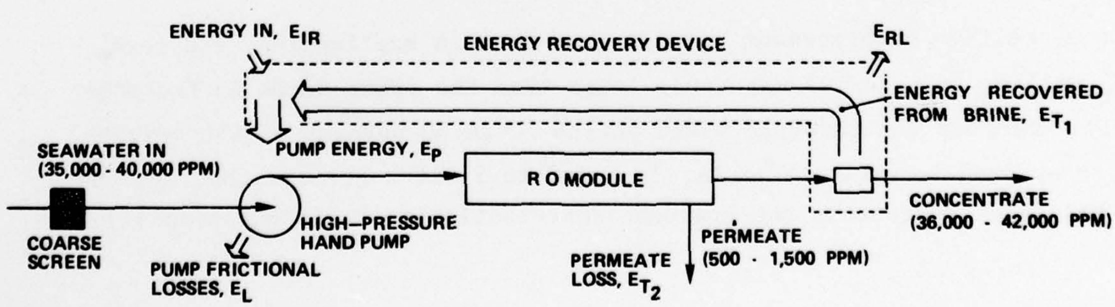


Figure 3 - Manually Operated Reverse Osmosis System With Energy Recovery

EVALUATION OF REVERSE OSMOSIS DESALINATORS
IN NAVY LIFE RAFTS

Two types of RO desalinators were operated in Navy Mark 5 life rafts in a pool and then subsequently in the open ocean. The objectives of these investigations were to demonstrate that such a desalinator could in fact be operated in a life raft under various conditions and to determine what modifications should be incorporated into subsequent desalinator designs to improve the performance and ease of operation of the units. Of the two desalinators investigated, one type incorporated an energy recovery device. The desalinators are shown in Figures 4 and 5.

1. Pumping Handle
2. Permeate Line
3. Coarse Screen Strainer
4. Pressure Sensing Device
5. Feed Brine Line

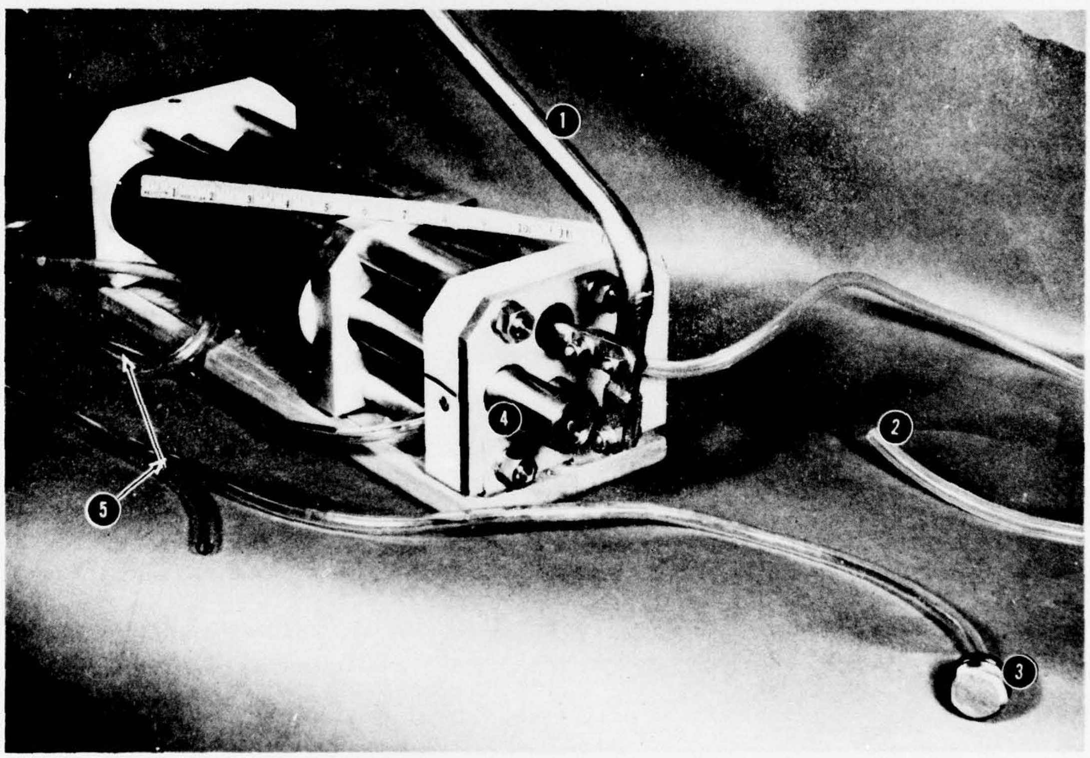


Figure 4 - Reverse Osmosis Desalinator
Incorporating Energy Recovery Device
(Unit 1)

1. Curved Handle
2. Pressure Gage
3. Pressure Relieving Device
   (Relief Valve)

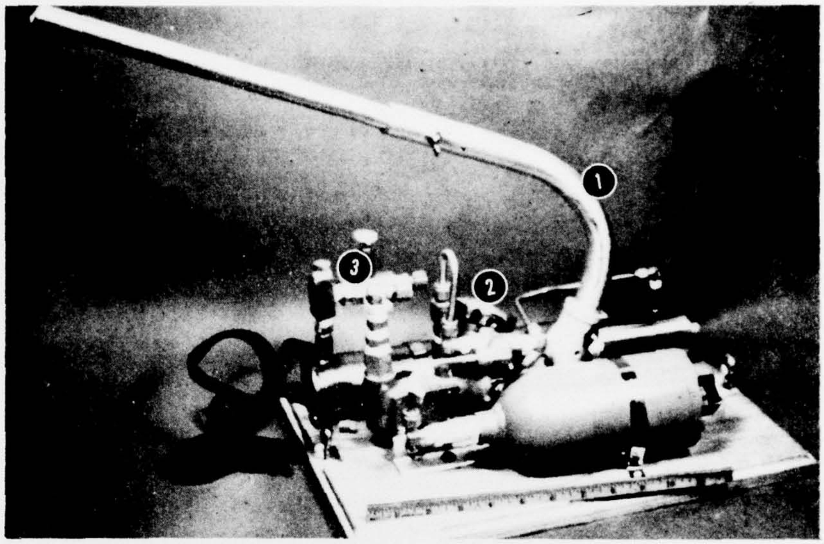


Figure 5 - Reverse Osmosis Desalinator
Without Energy Recovery Device
(Unit 2)

The desalinator shown in Figure 4, designated as Unit 1, incorporates an energy recovery device. The approximate dimensions of the unit are 6 inches wide by 5½ inches high by 16 inches long (not including the handle). Weight of the desalinator is 22 pounds. During the life raft tests, a wooden pad 1-inch-thick with rounded corners was mounted to the bottom of the unit to protect the operators from the sharp machined edges of the desalinator bottom. To operate the desalinator, the combined feed/brine overboard line must first be lowered into the seawater. The operator then begins stroking the pump handle at a moderate speed to achieve an operating pressure of 800 to 1,000 psig as shown on the pressure indicator. The pressure indicator shown in Figure 4 is a small calibrated rod which moves into or out of the circular housing as the operating pressure decreases or increases, respectively. For nighttime operation when this indicator is not visible, the pressure indicating device has a built-in

pressure relief valve which relieves overpressures with a fine mist of seawater, thereby creating a hissing sound. During nighttime operation, the unit operating pressure would be maintained by stroking the pump handle at a rate where the relief valve just begins to open as would be evident by the hissing sound. In actual at-sea situations this may not be a feasible approach and thus, another technique may have to be developed.

The desalinator without an energy recovery device, designated as Unit 2, is shown in Figure 5. The unit has a 1/2-inch-thick (12.2 mm) wooden base to which are fastened the components of the desalinator. The approximate dimensions of Unit 2 are 11 inches wide by 16 inches long by 8 inches high and weighs 26 pounds. Unit 2 is deployed in a similar manner to Unit 1, except that the pump pressure is maintained by watching a dial-type pressure gage. Nighttime operation would be dependent upon utilizing a gage with a luminous dial and indicator needle. The gage supplied with Unit 2 was suitable for daytime operation only.

## LIFE RAFT DESALINATOR EVALUATIONS IN A POOL

### Unit 1 Operation

The first desalinator evaluated in a Mark 5 life raft in a pool was Unit 1, the energy recovery desalinator. These tests were conducted using four Navy enlisted men (two chiefs and two third classmen). After a brief instruction period on operation of the unit, each man was instructed to pump the unit in the life raft as long as he could comfortably do so. During that period of time the permeate output, the permeate quality, and the operating time per man were recorded. During all tests conducted, actual seawater from the Norfolk, VA area was used. A container filled with seawater was placed outside of the life raft on the side of the pool and feed and brine lines were attached to the desalinator from the container.

Table 1 shows the results of tests on Unit 1. On the first day, tests 1 through 4 were conducted with a 31,000 ppm total dissolved solids seawater solution. The remaining tests were conducted on the second day using a 34,000 ppm total dissolved solids seawater solution.

TABLE 1 - RESULTS OF POOL TESTS ON THE ENERGY RECOVERY DESALINATOR (UNIT 1) IN A MARK 5 LIFE RAFT

| Test No. | Operator No. | Unit Output (gal/h) | Permeate Quality (ppm) | Operating Time (min) | Remarks | |
|---|---|---|---|---|---|---|
| 1 | 1 | 1.9 | 400 | 12 | Day 1 testing | Testing |
| 2 | 2 | 1.5 | 550 | 15.5 | feedwater | conducted with |
| 3 | 3 | 1.4 | 550 | 5 | quality 3.1% salt | 20-inch |
| 4 | 4 | 1.8 | 500 | 10 | | lever arm |
| 5 | 2 | 1.3 | 500 | 10 | | |
| 6 | 3 | 1.1 | 550 | 5 | | |
| 7 | 1 | 1.1 | 550 | 10 | | |
| 8 | 4 | 1.0 | 600 | 10 | Day 2 testing | |
| 9 | 2 | 1.7 | 500 | 10 | feedwater | |
| 10 | 3 | ND | 650 | 10 | quality 3.4% salt | Testing |
| 11 | 1 | ND | ND | 10 | | conducted with |
| 12 | 4 | 1.3 | 600 | 10 | | 32-inch |
| 13 | 2 | 1.5 | 525 | 25 | | lever arm |
| 14 | 1 | 1.7 | 500 | 25 | | |
| 15 | 4 | 1.3 | 700 | 15 | | |
| Average | --- | 1.4 | 548 | 12.2 | | |

ND = No Data

As can be seen from the results in Table 1, the desalinator was easily operated in the life raft for durations up to 25 minutes. Permeate output varied between 1.0 to 1.9 gal/h, and quality varied between 400 and 700 ppm total dissolved solids. The performance of the desalinator changes with the pumping rate of the unit, which accounts for much of the scatter in the data. When the pump is stroked at a slower rate, the permeate quality and quantity will decrease. This reduction is a result of the lower water flow rate across the membrane and the lower operating pressure, both of which influence the salt rejection and permeate rate of the membrane. Ideally, the operator should pump just below the rate at which the relief valve will open. In actual operation, most operators will probably tend to stroke at a rate somewhat less than the ideal because less energy is required.

During the initial seven test runs, a 20-inch pump handle was used with Unit 1 desalinator. During these test runs, the test personnel indicated that the force required to operate the lever arm was considerable and recommended lengthening it. During the remaining test runs, a bar was added to increase the effective length of the handle to 32 inches. When the lever arm is increased the actual work required to operate the unit is not affected since the strokes per minute and the torque should remain constant. Subjectively, the operators of Unit 1 felt unanimously that the general ease of operation of the desalinator was enhanced by the longer

handle. This would seem to be verified by the longer operating times that were achieved during later runs. Part of this improvement in time, however, might also be a result of experience gained in manual pumping and subsequent improvement in pumping technique.

Unit 2 Operation

The Unit 2 RO desalinator was also operated in the Mark 5 life raft. This desalinator required operation by two men because of the large force necessary to operate the high-pressure pump. Figure 6 illustrates the two positions used in operating Unit 2. Essentially, one man was required to hold the unit down on his lap while the other operated the pump. Figure 6a shows operation of the desalinator with a straight handle while Figure 6b shows operation of the unit with a curved handle.

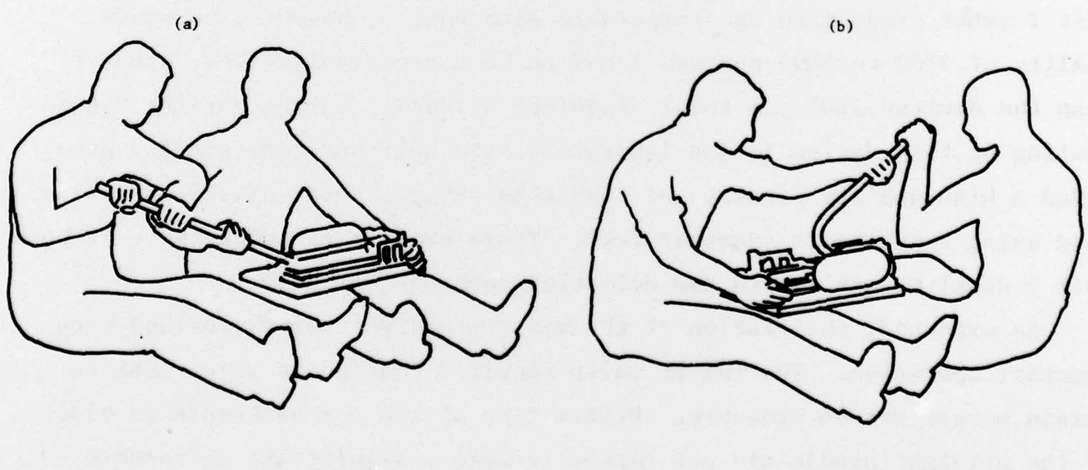


Figure 6 - The Two Positions Used in The Operation of Unit 2 Aboard the Mark 5 Life Raft

This desalinator utilizes a throttling device to regulate RO module pressure. Two different types of throttle mechanisms were employed. One of the mechanisms was a relief-type valve. Theoretically, when the operating pressure exceeds a predetermined value (800 to 1000 psig) the valve rises off the seat and relieves the system overpressure. A possible disadvantage of this type of valve is that some operator adjustment may be required. The second device used to throttle the seawater was a fixed restrictor type of device - actually a calibrated orifice. The advantage of the orifice is that it regulates system pressure but does not require constant operator attention. The disadvantage is that the orifice is subject to plugging by small particles, which could render the system inoperative. Open ocean water, however, would not normally be expected to contain particles large enough to cause plugging of the restrictor device.

Table 2 contains the test results of Unit 2. Actually, two Unit 2 desalinators were tested. The first one tested (tests 1 and 2) was operated with the orifice and a curved pump handle, while the second desalinator tested (tests 3 through 6) utilized a pressure relief valve and a straight operating handle. In these tests, the men were asked to operate the desalinator as long as possible but a minimum of at least 5 minutes. As can be seen in Table 2, all tests were only run the minimum 5 minutes because of the prohibitively high manual energy requirements. Unit 2 water production was comparable with Unit 1; however, permeate quality of 3700 to 5000 ppm was found to be unacceptable (i.e., greater than the desired 1500 ppm total dissolved solids). During earlier bench testing of this device in the laboratory, the unit had consistently provided a high quality permeate of less than 300 ppm total dissolved solids when using a synthetic seawater feed. Therefore, it is suspected that both Unit 2 desalinators tested had defective membrane modules.

As expected, utilization of the restrictor type valve provided much smoother operation. The relief valve required continuous adjustment to attain proper system pressure. Utilization of the curved handle in place of the straight handle did not appear to make a significant difference to the operators of the unit. The unit was prohibitively difficult to operate with either handle. The operators complained throughout each period of operation that the work required was excessive.

TABLE 2 - RESULTS OF POOL TESTS ON THE NONENERGY RECOVERY DESALINATOR (UNIT 2) IN A MARK 5 LIFE RAFT

| Test No. | Operator No. | Unit Output (gal/h) | Permeate Quality (ppm) | Operating Time (min) | Remarks |
|---|---|---|---|---|---|
| 1 | 3,4 | 1.3 | 5000 | 5 | Restrictor valve and curve handle |
| 2 | 1,2 | 1.3 | 4000 | 5 | |
| 3 | 3,4 | 0.9 | 3700 | 5 | Relief valve and straight handle |
| 4 | 1,2 | 1.1 | 4000 | 5 | |
| 5 | 3,4 | 1.4 | 4700 | 5 | |
| 6 | 1,2 | 1.1 | 5000 | 5 | |
| Average | --- | 1.2 | 4400 | 5 | |

NOTE: Approximate seawater total dissolved solids - 3.5 percent

LIFE RAFT - OPEN OCEAN TESTING

Open ocean testing was accomplished to demonstrate that the RO emergency desalinator could be successfully operated in a life raft under actual sea conditions. In these tests only Unit 1, the energy recovery desalinator, was tested since its performance in the initial pool testing was far superior to that of Unit 2. A Mark 5 life raft was dropped into the ocean approximately 15 miles south of Eleuthera Island (Bahamas). The life raft was secured to the Navy ship MONOB (YAG 61) by 400 feet of line. Two of the MONOB crew and one of the authors remained in the life raft from 0830 to 1600 hours on 30 January 1979, with a Unit 1 desalinator similar to the one used in the previous pool testing. The sea state ranged from approximately 2 feet in the morning to 4 feet in the afternoon. The men were initially instructed on how to operate the unit. They then took turns throughout the day with each man operating the unit once per hour.

Table 3 gives the result of these tests. As can be seen, the unit consistently provided suitable quality water at a rate of 1.1 to 1.4 gal/h. Permeate rates and permeate quality decreased in successive tests. This reduction is believed to be a result of increased operator fatigue as tests were continued throughout the day. It can be seen that performance was also a strong function of which man operated the unit. Operator 6 consistently achieved better water quality and quantity since he pumped the unit at a slightly faster rate than Operator 5.

TABLE 3 - RESULTS OF OPEN OCEAN TESTS OF THE ENERGY RECOVERY DESALINATOR (UNIT 1) IN A MARK 5 LIFE RAFT

| Test No. | Operator No. | Unit Output (gal/h) | Permeate Quality (ppm) | Operating Time (min) |
|---|---|---|---|---|
| 1 | 5 | 1.4 | 1200 | 10 |
| 2 | 6 | 1.4 | 1050 | 30 |
| 3 | 5 | 1.3 | 1200 | 35 |
| 4 | 6 | 1.4 | 1050 | 10 |
| 5 | 5 | 1.2 | 1400 | 15 |
| 6 | 6 | 1.3 | 1150 | 18 |
| 7 | 5 | 1.1 | 1450 | 15 |
| 8 | 6 | 1.2 | 1250 | 15 |
| 9 | 5 | 1.2 | 1250 | 30 |
| 10 | 6 | 1.2 | 1350 | 30 |
| 11 | 5 | 1.1 | 1375 | 10 |
| 12 | 6 | 1.2 | 1350 | 10 |
| Average | --- | 1.25 | 1256 | 19 |
| NOTE: Approximate seawater total dissolved solids - 4.0 percent | | | | |

Most importantly, these results indicate that a man can operate this device in a life raft in the open ocean with a moderate sea state. The men operated the desalinator for as long as 35 minutes at one time and were able to sustain this operation during the 7 1/2 hour test period. The average water product rate was 1.25 gal/h (30 gal/d) with an average permeate quality of 1256 ppm total dissolved solids. Each man over the 7 1/2 hour test period operated the unit for almost 2 hours. For a 25-man life raft, each man in a 24-hour period would be required to operate such a desalinator for 1 hour at most (total operating time per day).

The permeate total dissolved solids levels measured were much higher than results from previous pool testing. As already mentioned, the desalinator used in the open ocean test was not the same unit tested in the pool and, therefore, did not have the same membrane module. Although some variation could be a result of differences in membrane performance for the two units, most of the difference is attributed to the higher seawater salinity. It was found that the open ocean seawater was somewhat higher in total dissolved solids (40,000 ppm) than previously experienced with coastal seawater used in the pool tests. Higher seawater salt content will result in a permeate with higher salt content and an increase in manual energy requirements. It was noticed by the author that greater effort was, in fact, required to operate the desalinator in the more saline open ocean seawater then previously experienced with the less saline coastal seawater. Later bench testing of the desalinator will include a study of the variations in power requirements and permeate salt content with feed seawater salinity.

## UNIT 1 OPERATING POSITIONS

During testing of the Unit 1 desalinator in the life raft, several operating positions were found suitable for comfortable operation. Figure 7 illustrates these various positions. Figure 7a is a view of the originally expected operating position. The man sits on the floor of the raft, possibly resting his back on the life raft sidewall with the desalinator placed across his lap. The handle is held by the right hand for support, and the left hand is used for applying the necessary operating force. Almost all of the work force is applied in the downward direction (the upward direction being a suction stroke). A similar position is shown in Figure 7b with the operator's legs crossed. Except for the sharp edges rubbing the operator's legs, this position was preferred to that of Figure 7a. Another alternative is shown in Figure 7c. The desalinator is positioned diagonally across the operator's legs, which allows the unit to be stroked in the more natural diagonal pulling motion.

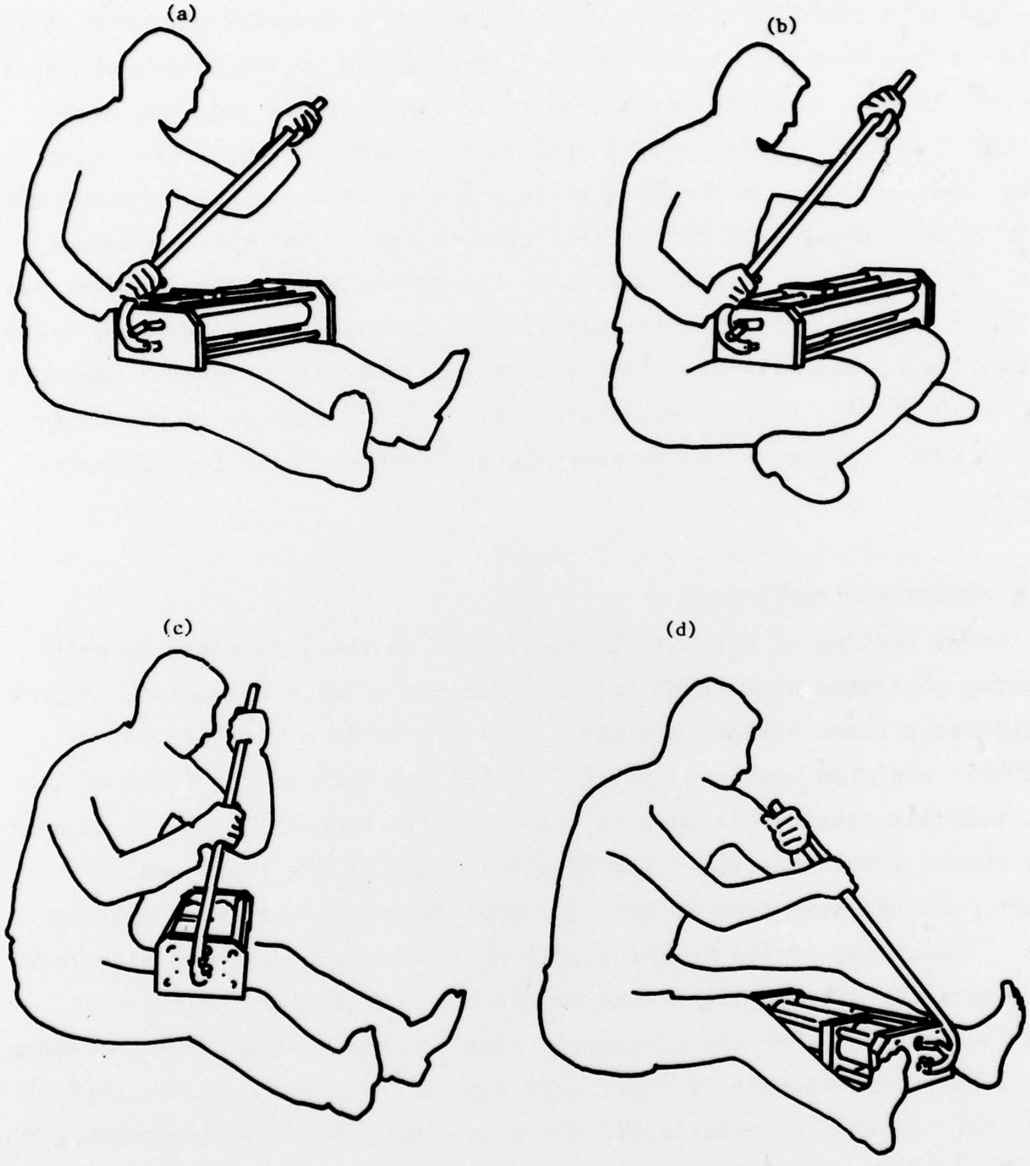


Figure 7 - The Four Positions Used in the Operation of Unit 1 Aboard the Mark 5 Life Raft

During at-sea testing where somewhat greater effort was required, the position shown in Figure 7d was preferred. In this position, the desalinator is placed between the legs on the raft floor. The handle is stroked as illustrated with the more natural pulling motion. During operation, the force applied to the handle is transmitted to the floor of the life raft. During testing, no rubbing or chaffing motion on the life raft floor was noted. One problem cited with this mode of operation was that the machined edge of the desalinator tended to dig into the skin on the inside of the legs, which was uncomfortable. This position (Figure 7d) appears to be the best one to use.

## CONCLUSIONS AND RECOMMENDATIONS

Of the two RO desalinators evaluated in actual life raft testing, the desalinator incorporating the energy recovery device far outperformed the desalinator without this feature. These evaluations successfully demonstrated that such a desalinator could, in fact, be operated in a life raft in the open ocean in choppy sea conditions with relative ease. During at-sea operation, the unit provided 1.1 to 1.4 gal/h of suitable quality water (less than 1,500 ppm of total dissolved solids) while being operated by one man at an acceptable expenditure of energy.

During the evaluation of the Unit 1 desalinator, a number of design improvements were recognized which would enhance the operation of the unit. These recommended modifications include:

1. Increase Pump Suction Size. One mechanical problem which surfaced during the investigations on the life raft (in both the pool and open ocean) was that the operator tended to pump the unit excessively fast on start-up because of the low initial pumping resistance. As a result, pump cavitation occurred and the operator was unable to achieve a high enough operating pressure to produce drinking water. The operator had to be told on start-up to reduce his pumping rate in order to avoid the cavitation and achieve the normal operating pressure. This problem can be eliminated in future desalinator designs by increasing the size of the pump suction.

2. <u>Lengthen Handle</u>. As previously mentioned, operators preferred the lengthened handle on Unit 1. Either a lengthened handle or preferably a telescoping handle with a detent to hold it in position should be incorporated into a new desalinator design.

3. <u>Increase Pump Stroke Rate</u>. The operators of the unit found that the 16 to 20 stroke cycles per minute required to maintain the operating pressure was too slow to sustain a natural rhythm. It was suggested by most of the operators that a pumping rate of 30 to 35 strokes per minute would be more comfortable. This can be achieved by reducing the pump piston diameter. The reduced piston size will reduce the force required per stroke and thus will permit an increase in the stroking rate without a net increase in energy required.

4. <u>Remove All Sharp Corners</u>. It was found that in most of the operating positions used, the sharp machined edges of the sides of the desalinator (the bottom was covered by a wooden pad) tended to dig into the legs of the operator making long-time operation of the unit uncomfortable. Future designs should eliminate sharp edges.

5. <u>Lengthen Unit</u>. In some of the positions used to operate the unit, it was suggested by the operators that the unit would be easier to pump if the unit were longer. In some positions, the edges of the unit actually rested on the operators legs, which caused discomfort during operation. Designing the unit to be thinner and longer would alleviate this problem.

Further development of an RO desalinator without an energy recovery device is not recommended for shipboard life raft application. Such development might be considered for a very low output RO desalinator which would need very little manual energy, as for example a desalinator for aircraft survival bags (for 1 to 2 persons).

It is clear that water rations in Navy life raft survival bags are inadequate, but that one of the two desalinators evaluated (Unit 1) could provide all water requirements for survival purposes. In view of the demonstrated performance of the present energy recovery RO desalinator in actual life raft testing, it is recommended that the Navy pursue an operational evaluation testing program leading to the incorporation of RO desalinators in life raft survival bags. The desalinators would be

utilized as the primary water source with some canned water being kept aboard for ready reserve.

## FUTURE PLANS

A contract is presently in process to redesign the present energy recovery desalinator to reduce cost, weight, volume, and to incorporate the design changes recommended in this report. The present unit will undergo performance testing to determine such operating characteristics as water output, water quality, and energy requirements as well as expected life of the unit. Present design goals call for a unit that will produce at least 0.5-gallon per man per day (12.5 gal/d for a 25-man raft) of water of salinity no greater than 1500 ppm of total dissolved solids. The unit must operate continuously without failure for at least 100 hours. It is expected that the RO module would not be changed between inspections of the life raft package, which is currently about once every 2 to 5 years.

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